NACA RM L53F02

NACA

RESEARCH MEMORANDUM

A TRANSONIC WIND-TUNNEL INVESTIGATION OF THE EFFECT OF MODIFICATIONS TO AN INDENTED BODY IN COMBINATION WITH A 45° SWEPTBACK WING

By Donald L. Loving

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

September 22, 1953

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

A TRANSONIC WIND-TUNNEL INVESTIGATION OF THE EFFECT OF MODIFICATIONS TO AN INDENTED BODY IN COMBINATION WITH A 45° SWEPTBACK WING

By Donald L. Loving

SUMMARY

Modifications to an indented body which was originally designed on the basis of the transonic drag-rise rule have been investigated to determine the effects on the aerodynamic characteristics of a 45° sweptback-wing—body combination. The investigation covered the Mach number range from 0.80 to 1.12 at angles of attack from -7° to 12° in the Langley 8-foot transonic tunnel. The wing had an aspect ratio of 4, a taper ratio of 0.6, and NACA 65A006 airfoil sections. Three modified indentations to the original indented body were investigated. The modifications were applied to only the upper half of the body. Modifications to only the lower half were simulated by obtaining data from the same configurations at negative angles of attack.

A comparison of the results with those for a symmetrical body indented on the basis of the transonic drag-rise rule has indicated that the drag of wing-body combinations can be significantly reduced at lifting conditions by modifying the indentation on both the upper and lower halves of the body. In general, for the present investigation the largest reductions in drag and the largest value of maximum lift-to-drag ratio were obtained through the effect of an abrupt indentation on the lower half of the body at the leading edge of the wing-body juncture followed by a bump in the indentation near the trailing edge of the wing. This modification resulted in a peak $(L/D)_{max}$ value which was 19.1 percent higher than the value for the indentation designed on the basis of the transonic drag-rise rule. A forward shift in the center of pressure was produced at transonic speeds by the various indentation modifications.

[redacted]

INTRODUCTION

Symmetrically indented bodies, designed on the basis of the transonic drag-rise rule (ref. 1), have been tested in combination with wings of varying plan form, sweep, aspect ratio, and thickness to improve the transonic drag-rise characteristics of wing-body combinations primarily at nonlifting conditions. (See refs. 2, 3, and 4.) For these investigations, the bodies were indented in the region of the wing-body juncture such that the cross-sectional area of the body of revolution was reduced by an amount equal to the exposed frontal area of the wing at the same axial station. Indenting the bodies in this manner produced wing-body configurations which had axial cross-sectional-area distributions equivalent to the area distribution of the original body alone. The results presented for these configurations have indicated that drag-rise reductions of the order of those obtained for the nonlifting case near the speed of sound may be obtained also at moderate lift coefficients.

This paper presents the results of a force-test investigation of a 45° sweptback-wing—body combination with modified body indentations giving asymmetrical bodies which were expected to improve the drag due to lift without penalizing results for the nonlifting case. The design of the modifications was not dictated entirely by the transonic drag-rise rule. These indentations were designed on the basis of known flow phenomena for sweptback wings at lifting conditions as obtained from the investigation reported in references 5 and 6. Three modifications to the symmetrical body indentation (tested and reported in ref. 2) were investigated. The investigation was conducted at Mach numbers from 0.80 to 1.12 for an angle-of-attack range from -7° to 12° in the Langley 8-foot transonic tunnel.

CONFIGURATIONS AND METHODS

Models

The steel wing of this investigation had 45° of sweepback, an aspect ratio of 4, a taper ratio of 0.6, and NACA 65A006 airfoil sections parallel to the plane of symmetry. This wing and the basic body of the combinations tested are the same as those employed in the investigation of the effect of a symmetrically indented body on the aerodynamic characteristics of the 45° sweptback-wing—body combination as reported in reference 2. The body modifications of the present investigation were accomplished by varying the indentation of the upper half of the body in the region of the wing from that specified by the transonic drag-rise rule. The shape of the lower half of the body was maintained in its original indented form (as specified by the transonic drag-rise rule for the

45° sweptback wing). The three asymmetrical sections investigated in conjunction with the wing have been designated modifications A, B, and C as shown in figures 1(a) and 1(b). The modifications were characterized by a more abrupt indentation at the forward portion of the contour than that of the basic indented body. As shown in figure 1(b), the maximum slope of this indentation was about twice that of the indentation designed according to the transonic drag-rise rule. For modification A, a cylindrical section, 2.5 inches in length, followed this abruptly indented portion of the body. Modification B was a variation on modification A and was characterized by a slight bump in the fuselage contour in the region of the trailing edge of the wing-body juncture. Modification C was similar to modification B with the exception of a larger bump in the contour. The rearward part of each modification was faired into the contour for the symmetrical indentation of reference 2. Where discontinuities in the cross section of the body occurred, because the upper half of the body was modified, the discontinuities were faired out with straight lines as shown in figure 1(a). Ordinates for the various body shapes are given in table I. The ratio of the maximum cross-sectional area of the body to the wing area was 0.0767 to 1.

These modifications were constructed of a combination of wood, Fiberglas, and plastic. The surface of the model was maintained in a smooth condition throughout the investigation. Details of the location of the model in the tunnel are presented in figure 2. The models were sting supported in the manner shown in figure 2. Photographs of the model installed in the test section are shown in figure 3.

Measurements and Accuracy

Forces and moments were measured by means of electrical strain-gage-type balances. The accuracy of the strain-gage measurements of the various models tested is shown in table II. These are maximum-error values. Actual errors are usually less.

Angles of attack were measured with the use of an electrical strain-gage unit mounted in the nose of the model (see ref. 3) and are considered to be correct to within ±0.1°.

The static pressure at the rear of the models was obtained from pressure orifices located in the top and bottom and two sides of the sting support in the plane of the model base. All data presented have been adjusted for model base drag, the coefficients having been adjusted to a condition at which the base pressure is equal to the free-stream static pressure; therefore, the results do not include drag due to the base of the model.

The accuracy of the free-stream Mach numbers presented herein is within ±0.003.

RESULTS AND DISCUSSION

The average Reynolds number for these tests covered the range from approximately 1.92×10^6 to 1.99×10^6 as shown in figure 4. These values are based on a mean aerodynamic chord of 6.125 inches.

The body used in this investigation does not simulate an airplane fuselage. The results, however, are indicative of the trends which may be expected if such modified indentations as were tested were incorporated in the design of an actual airplane.

The basic data for the modifications are presented for the wing-body combinations in figures 5 to 7 in the form of angle of attack, drag coefficient, and pitching-moment coefficient against lift coefficient, respectively. The pitching moments were obtained about the 0.25 chord of the mean aerodynamic chord. Data for the wing on the symmetrically indented body have been presented previously in reference 2. Analysis plots of the aerodynamic characteristics of the wing-body combinations are presented in figures 8 to 12.

The results obtained for modification B were similar to but less pronounced than those for modification C; therefore, specific mention of modification B will not be made.

<u>Lift</u>.- When the effects on lift of the various modifications tested, as shown in figure 8, are compared with the results of the symmetrical indentation of reference 2, it may be seen that modification A created an increase in lift at transonic and supersonic speeds for all positive angles of attack tested. It is believed that this increase in lift may be attributed to the greater lift over the forward portion of the inboard wing sections resulting from an increase in the induced velocities associated with the rather abrupt indentation of the body at the leading edge of the wing-body juncture. Addition of the bump to the contour, as for modification C, reduced the effect of the abrupt indentation and resulted in a lower lift than for modification A. This lower lift is believed to be due to an increased pressure field extending over the trailing-edge region of the inboard wing sections as a result of a deceleration of the flow over the bump. The reason for the increase in lift at subsonic speeds for modification C is not apparent at this time.

Even though data were obtained at negative angles of attack, it may be considered that these data were obtained at positive angles of attack for modifications to the bottom of the body. The results demonstrated by the data at angles of attack of -2° and -5° indicate that modification A increased the lift at Mach numbers above 0.99 and the bump in the contour (modification C) produced an additional increase in lift throughout the speed range. The reason for the increase in lift for modification A on the lower half of the body is not fully understood at the present time beyond the fact that it is associated only with phenomena at supersonic speeds. The additional increase in lift for modification C may be attributed to an increased pressure region on the lower surface of the wing produced by a deceleration of the flow over the bump in the contour.

Drag for nonlifting case.- The total drag coefficient at zero lift for body modification A was slightly lower than that for the symmetrically indented body in combination with wing (ref. 2) at Mach numbers between 0.87 and 1.005 and at a Mach number of 1.11, and slightly higher between Mach numbers of 1.005 and 1.09, as shown in figure 9. The total drag for the other modifications was slightly higher throughout the Mach number range. The drag, however, is still much lower than that for the original unindented-body configuration as observed by a comparison with the results for the cylindrical body with wing reported in reference 2. These data indicate that the indentation modifications for lifting conditions did not seriously penalize the nonlifting case (symmetrically indented body of ref. 2). For all modifications the drag rise between Mach numbers of 0.975 and 1.05 was greater than that for the symmetrically indented case of reference 2. This was more or less expected since the modifications were designed as a compromise between the shape specified by the transonic drag-rise rule and the shape believed desirable for lifting conditions.

Drag for lifting case.- The use of the abrupt indentation for modification A on the upper half of the body produced a reduction in the drag for lifting conditions at transonic speeds as shown in figure 9. A possible explanation for this may be as follows: The induced flow over the abrupt indentation of modification A decreased the pressure over the forward portion of the wing upper surface leading to a broader pressure peak and greater leading-edge suction on the wing without increasing the shock losses or separation effect. At the angles of attack for which data were obtained, flow surveys (ref. 6) have shown that separation existed at the leading edge of the wing for the unindented-body configuration; therefore, it may be assumed that separation existed at the leading edge of the wing for the symmetrically indented-body configuration.

This same abrupt indentation on the lower half of the body, as demonstrated by the data at negative lift coefficients, produced a larger reduction in drag at lifting conditions throughout the speed range due probably to less upflow over the body near the leading edge of the wing. It is believed that the reduction in upflow resulted in a lower pressure peak and less separation over the upper surface of the forward inboard portions of the wing, leading to lower drag due to lift. (The decreased upflow would also decrease the lift, but the results indicate that the drag reduction was greater in proportion than the lift.) This effect was not contemplated in the original design of this modification. Modification A on the lower surface not only reduced the separation but also reduced shock loss and its associated drag. This reduction is believed to be due to the production of expansion waves near the leading edge of the wing on the abruptly indented body which offset the compression waves normally associated with the increased pressure ahead of the lower surface of the wing. The favorable effects for both the negative and positive lift-coefficient ranges suggest that larger drag reductions might be obtained by using a shape similar to that of modification A for both the upper and lower halves of the body simultaneously.

The bump on the indentation on the upper half of the body had an unfavorable effect on the drag due to lift. This same bump on the lower half of the body was effective in reducing the drag at lifting conditions up to $M = 1.025$ as shown by the condition for modification C at negative lift coefficients in figure 9. It was reasoned that the bump on the lower half of the body tended to decelerate the flow and produce an increased pressure field over a large area of the inboard region of the wing lower surface. This resulted in a more favorable spanwise and chordwise distribution of load, which lead to lower drag due to lift.

Maximum lift-to-drag ratios.- In general, the values of maximum lift-to-drag ratio $(L/D)_{max}$ for the modifications on the upper half of the body were lower in the subsonic range compared with those for the symmetrically indented configuration of reference 2, as shown in figure 10. An increase in the value of maximum lift-to-drag ratio relative to the symmetrical indentation of reference 2 was obtained for modification A on the upper half of the body in the Mach number range from approximately 0.96 to 1.05. The peak value of $(L/D)_{max}$ was approximately the same for these two configurations, but the Mach number at which the maximum $(L/D)_{max}$ occurred was increased from 0.95 to 0.98 by modification A.

When the models with modifications A and C were tested at negative lift coefficients, simulating conditions which would occur if the modified indentations were on the lower half of the body at positive lift conditions, the values of $(L/D)_{max}$ were considerably larger than those obtained for either the changes to the upper half of the body or for the symmetrically indented body with wing combination of reference 2. The peak value of $(L/D)_{max}$, 13.7, was obtained for modification C. This value was 19.1 percent greater than that for the symmetrically indented configuration, as shown in figure 10.

The lift coefficient at which $(L/D)_{max}$ was obtained varied only slightly for the different indentation modifications. As Mach number was increased from 0.80 to 1.12, the average lift coefficient increased from approximately 0.27 to 0.32, with the greatest change occurring between Mach numbers of 0.975 and 1.05.

Pitching moment.- As shown in figure 7, the pitch-up characteristics were little affected by the different body indentations at positive lift coefficients. The magnitude of the pitching-moment coefficients changed slightly when the body shape was changed as shown in figure 11. At negative lift coefficients, the values for the modified indentations were more negative than those for the symmetrically indented-body configuration. At positive lift conditions, the pitching moments, in general, were more positive in the transonic range. These changes in pitching moment resulted from a forward movement of the center of pressure as shown in figure 12 especially for the condition of having the lower half of the body modified. For the positive lift conditions, these changes in pitching moment and center-of-pressure location are believed to be due to the increase in lift over the forward portion of the inboard sections of the wing associated with increased induced velocities over the abrupt indentation. For the negative lift conditions, the changes for modification A cannot be explained at the present time. The addition of the bump on the contour had no effect except in the transonic range for a lift coefficient of -0.2. For this condition, the increase in lift over the inboard portion of the wing due to the bump must have acted ahead of the aerodynamic center of the configuration, as indicated by the more forward location of the center of pressure.

CONCLUSIONS

A symmetrically indented body in combination with a 45° sweptback wing has been modified on the basis of known flow phenomena in an effort to improve the drag-rise characteristics of the combination at lifting conditions. The results of the force tests at transonic speeds lead to the following conclusions:

1. Significant reductions in the drag coefficient of the wing-body combination at lifting conditions were obtained through the use of modifications to the indentations on both the upper and lower halves of the body.

2. The greatest general reductions in drag and the largest value of maximum lift-to-drag ratio were obtained through the use of a rather abrupt indentation on the lower half of the body at the leading edge of the wing-body juncture followed by a bump on the indentation near the trailing edge of the wing. The peak $(L/D)_{max}$ value for this modification was 19.1 percent higher than that obtained for the indentation designed on the basis of the transonic drag-rise rule.

3. The center of pressure shifted forward at transonic speeds when the indentation was modified on the upper or lower half of the body.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 19, 1953.

REFERENCES

1. Whitcomb, Richard T.: A Study of the Zero-Lift Drag-Rise Characteristics of Wing-Body Combinations Near the Speed of Sound. NACA RM L52H08, 1952.

2. Robinson, Harold L.: A Transonic Wind-Tunnel Investigation of the Effects of Body Indentation, As Specified by the Transonic Drag-Rise Rule, on the Aerodynamic Characteristics and Flow Phenomena of a 45° Sweptback-Wing—Body Combination. NACA RM L52L12, 1953.

3. Williams, Claude V.: A Transonic Wind-Tunnel Investigation of the Effects of Body Indentation, As Specified by the Transonic Drag-Rise Rule, on the Aerodynamic Characteristics and Flow Phenomena of an Unswept-Wing—Body Combination. NACA RM L52L23, 1953.

4. Carmel, Mélvin M.: Transonic Wind-Tunnel Investigation of the Effects of Aspect Ratio, Spanwise Variations in Section Thickness Ratio, and a Body Indentation on the Aerodynamic Characteristics of a 45° Sweptback Wing-Body Combination. NACA RM L52L26b, 1953.

5. Loving, Donald L., and Williams, Claude V.: Basic Pressure Measurements on a Fuselage and a 45° Sweptback Wing-Fuselage Combination at Transonic Speeds in the Slotted Test Section of the Langley 8-Foot High-Speed Tunnel. NACA RM L51F05, 1951.

6. Whitcomb, Richard T., and Kelly, Thomas C.: A Study of the Flow Over a 45° Sweptback Wing-Fuselage Combination at Transonic Mach Numbers. NACA RM L52D01, 1952.

TABLE I.- BODY ORDINATES

[The radii of the lower halves of the modified bodies are the same as those of the symmetrically indented body of ref. 2]

Station, in.	Radius, in., for -			
	Symmetrically indented body (ref. 2)	Modification A, upper half	Modification B, upper half	Modification C, upper half
0	0	0	0	0
.225	.104	.104	.104	.104
.338	.134	.134	.134	.134
.563	.193	.193	.193	.193
1.125	.325	.325	.325	.325
2.250	.542	.542	.542	.542
3.375	.762	.762	.762	.762
4.500	.887	.887	.887	.887
6.750	1.167	1.167	1.167	1.167
9.000	1.391	1.391	1.391	1.391
11.250	1.559	1.559	1.559	1.559
13.500	1.683	1.683	1.683	1.683
15.750	1.770	1.770	1.770	1.770
18.000	1.828	1.828	1.828	1.828
20.250	1.864	1.864	1.864	1.864
22.500	1.875	1.875	1.875	1.875
[a]23.125	1.875	1.875	1.875	1.875
[a]23.625	1.864	1.850	1.850	1.850
[a]24.125	1.842	1.800	1.800	1.800
[a]24.625	1.815	1.740	1.740	1.740
[a]25.125	1.787	1.670	1.670	1.670
[a]25.625	1.751	1.610	1.610	1.610
[a]26.125	1.710	1.570	1.570	1.570
[a]26.625	1.673	1.560	1.560	1.560
[a]27.125	1.641	1.560	1.560	1.565
[a]27.625	1.614	1.560	1.568	1.580
[a]28.125	1.592	1.560	1.582	1.602
[a]28.625	1.572	1.560	1.600	1.630
[a]29.125	1.560	1.560	1.620	1.660
[a]29.625	1.563	1.563	1.630	1.690
[a]30.125	1.572	1.572	1.640	1.720
[a]30.625	1.592	1.592	1.650	1.730
[a]31.125	1.611	1.611	1.650	1.730
[a]31.625	1.628	1.628	1.650	1.730
[a]32.125	1.640	1.640	1.650	1.730
[a]32.625	1.647	1.647	1.650	1.730
[a]33.125	1.656	1.656	1.657	1.730
[a]33.625	1.671	1.671	1.671	1.730
[a]34.125	1.688	1.688	1.688	1.730
[a]34.625	1.708	1.708	1.708	1.735
[a]35.125	1.740	1.740	1.740	1.750
[a]35.625	1.772	1.772	1.772	1.772
[a]36.125	1.802	1.802	1.802	1.802
[a]36.625	1.830	1.830	1.830	1.830
[a]37.125	1.850	1.850	1.850	1.850
[a]37.625	1.864	1.864	1.864	1.864
[a]38.125	1.875	1.875	1.875	1.875
38.375	1.875	1.875	1.875	1.875
38.625	1.875	1.875	1.875	1.875
43.000	1.875	1.875	1.875	1.875

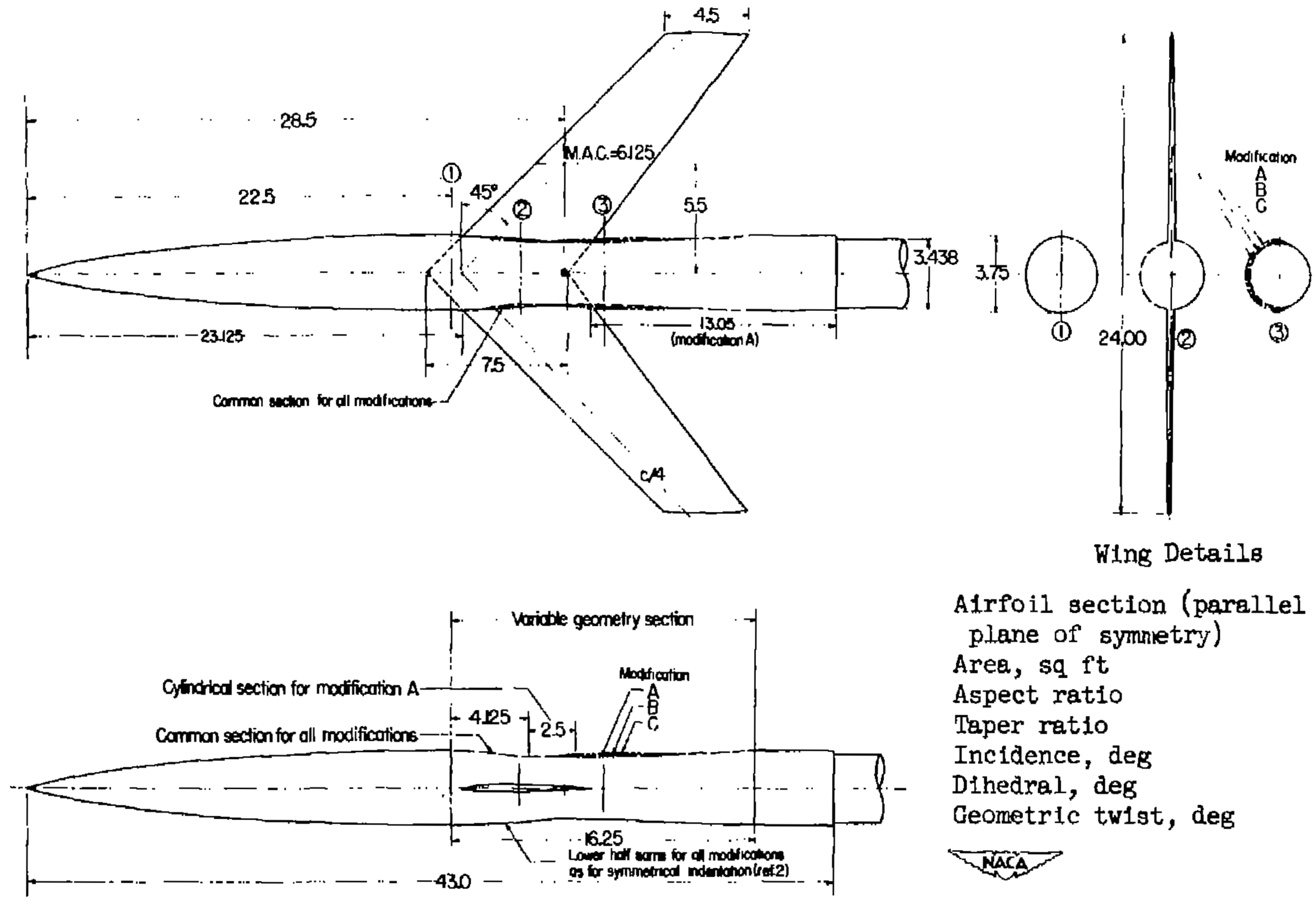
[a]Indented section.

NACA

TABLE II.- TYPICAL ACCURACY OF STRAIN-GAGE MEASUREMENTS

[Angle-of-attack range, -7° to 12°]

	$M = 0.60$	$M = 1.00$
Lift coefficient	±0.016	±0.008
Drag coefficient	±0.002 to ±0.005	±0.001 to ±0.003
Pitching-moment coefficient	±0.003	±0.002



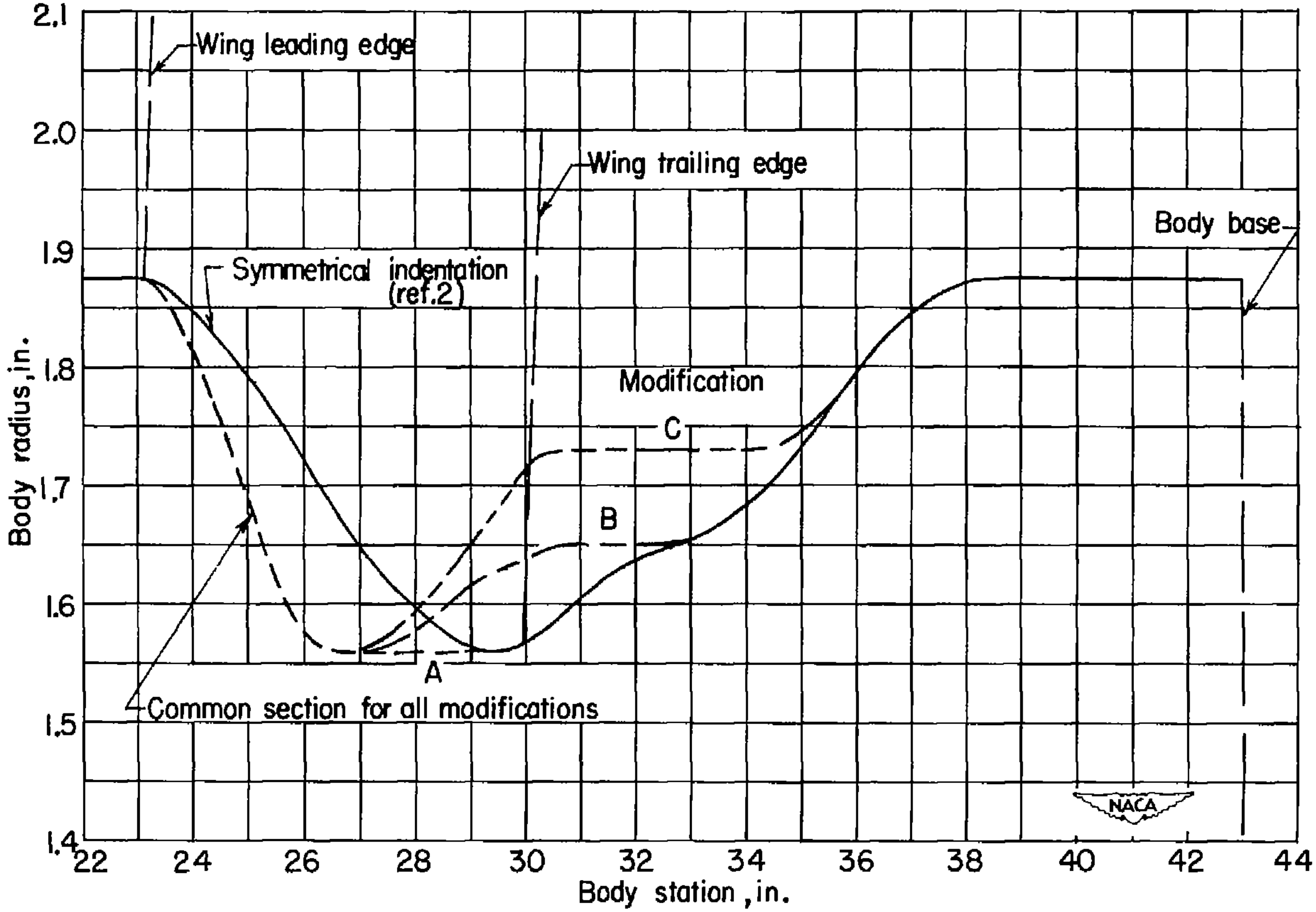
Wing Details

Airfoil section (parallel to plane of symmetry)	NACA 65A006
Area, sq ft	1
Aspect ratio	4
Taper ratio	0.6
Incidence, deg	0
Dihedral, deg	0
Geometric twist, deg	0

(a) Complete model.

Figure 1.- Details of configuration tested. All dimensions are in inches.

[redacted]



(b) Details of modifications.

Figure 1.- Concluded.

[redacted]

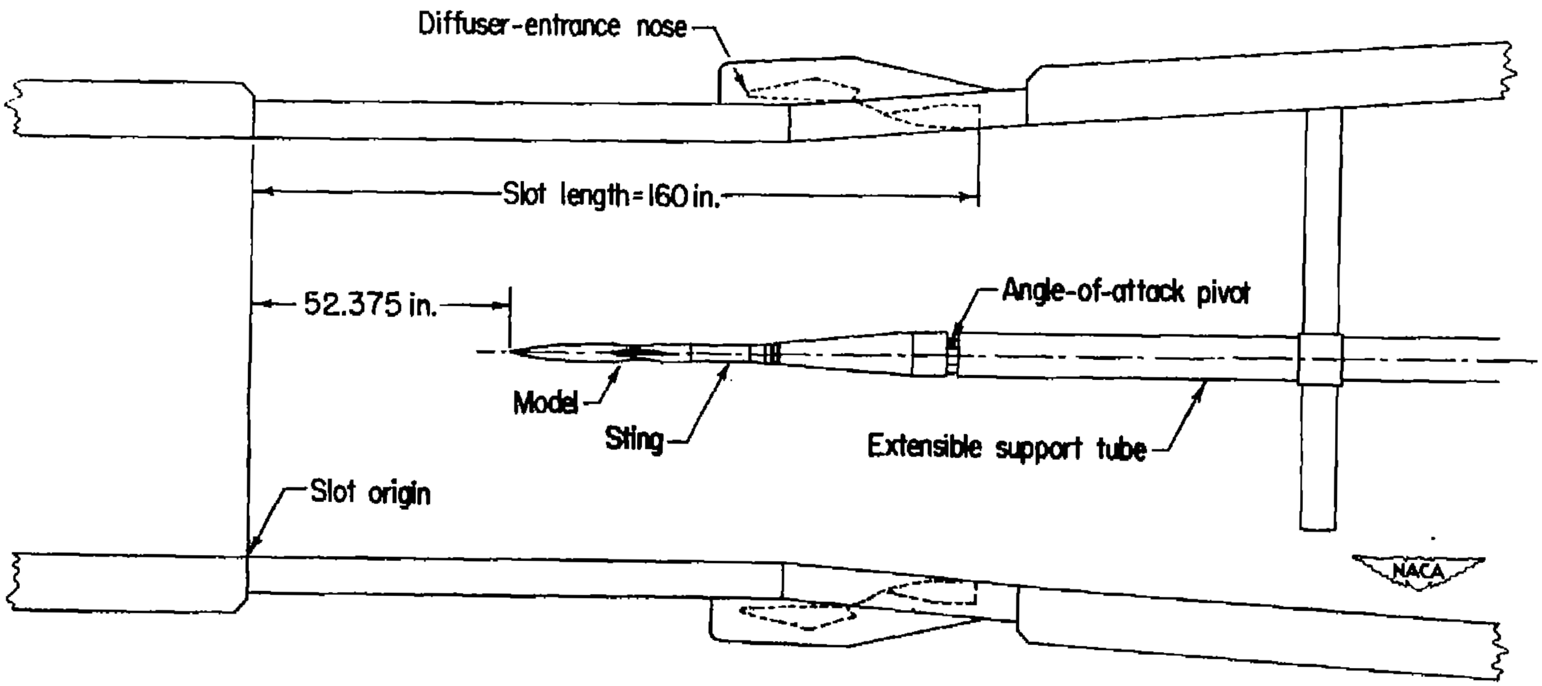
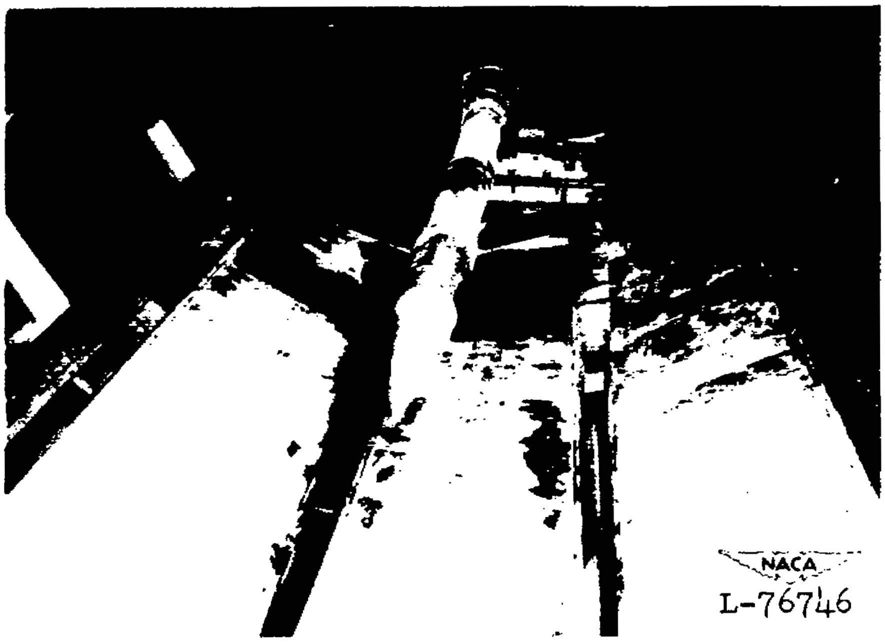


Figure 2.- Details of the location of the model in the Langley 8-foot transonic tunnel.



(a) Front view.

(b) Rear view.

Figure 3.- Model mounted in test section.

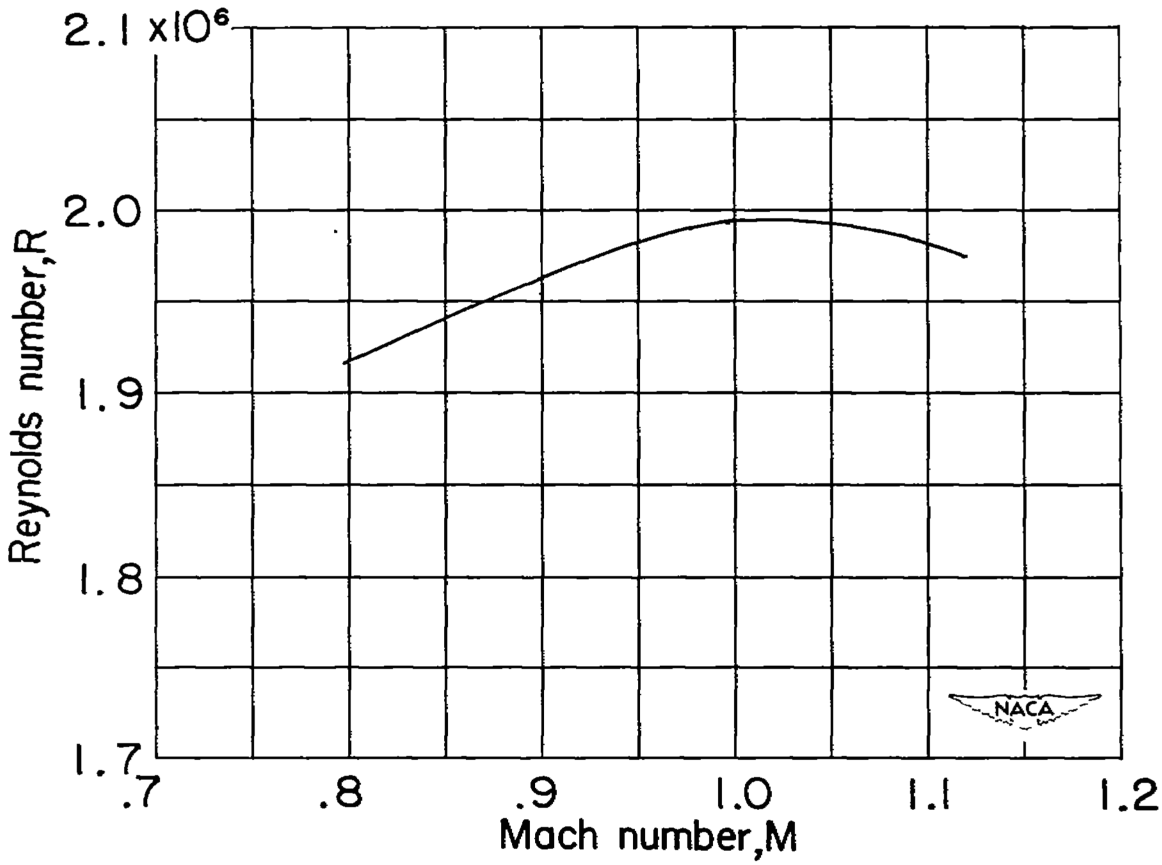
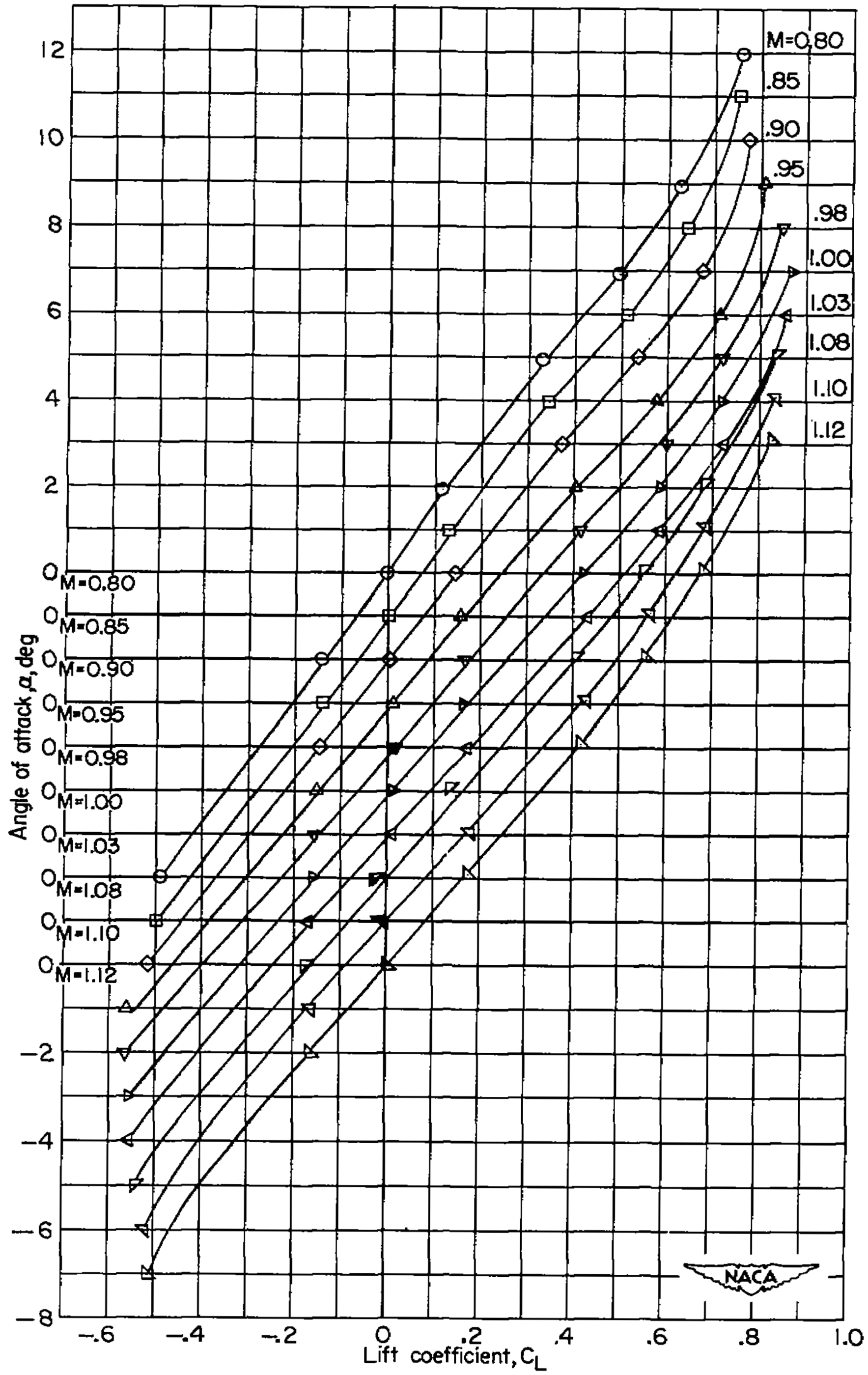
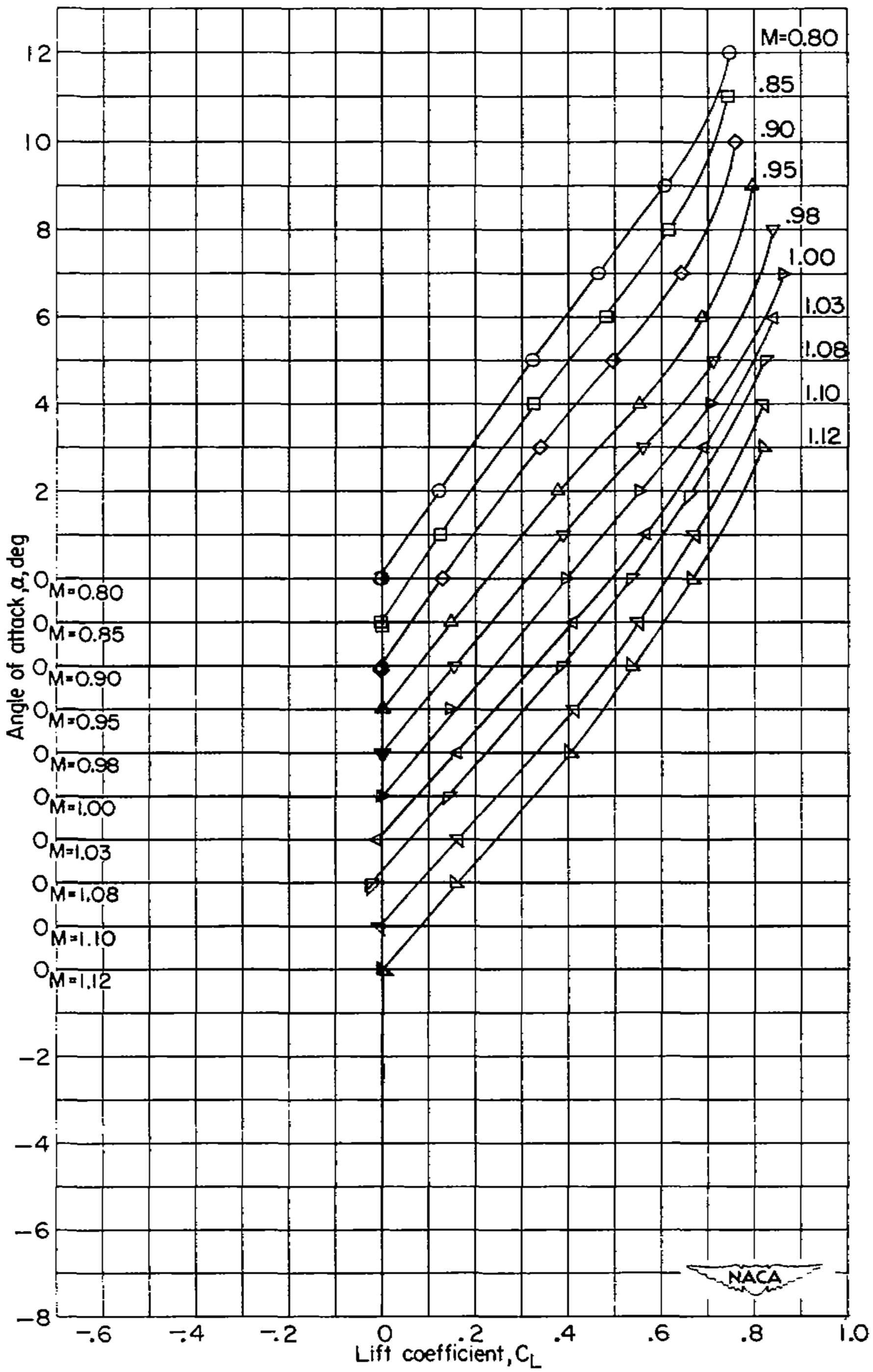


Figure 4.- Variation with Mach number of average Reynolds number based on a mean aerodynamic chord of 6.125 inches.



(a) Body modification A.

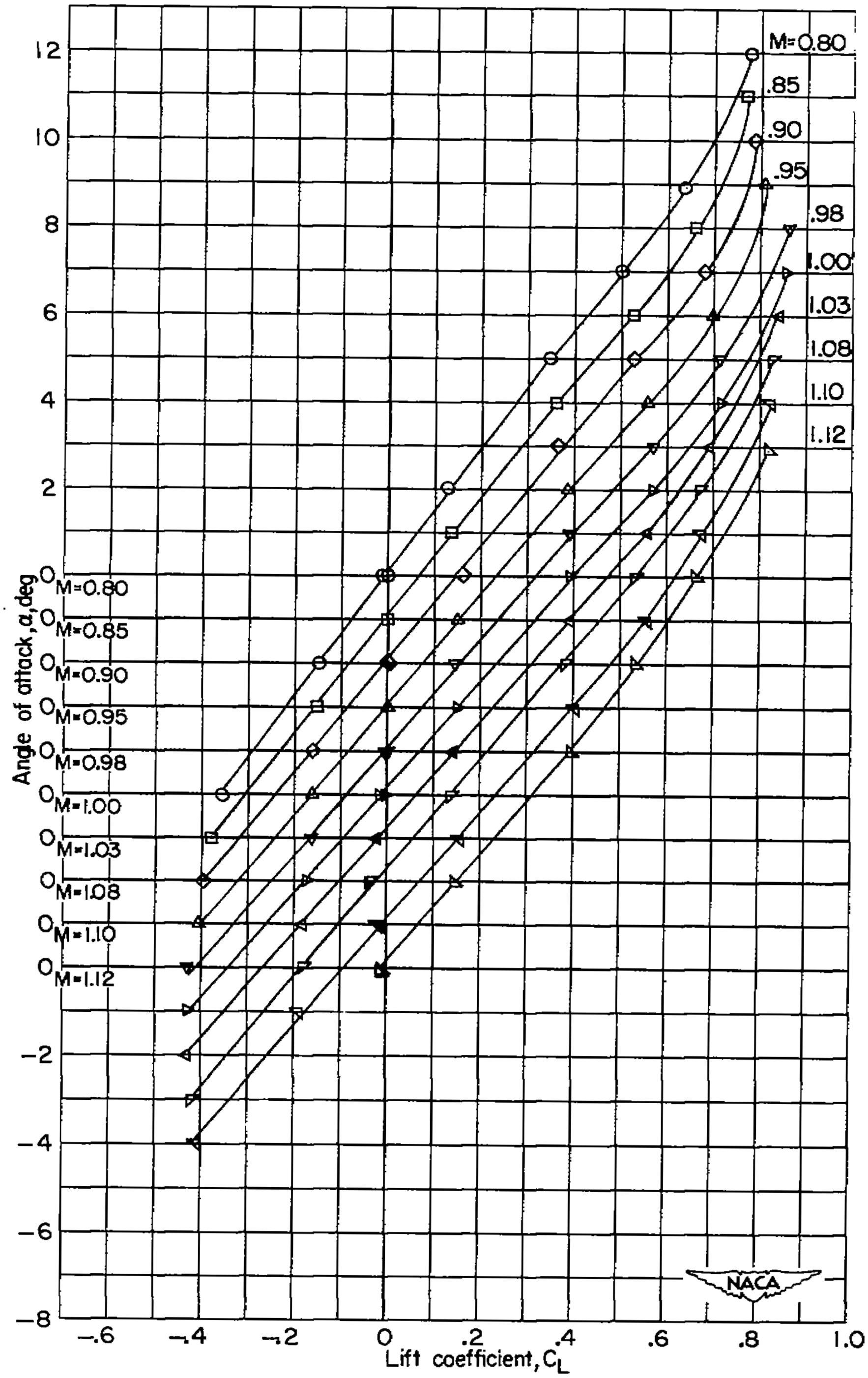
Figure 5.- Variation with lift coefficient of the angle of attack of the various wing-body combinations at Mach numbers from 0.80 to 1.12.



(b) Body modification B.

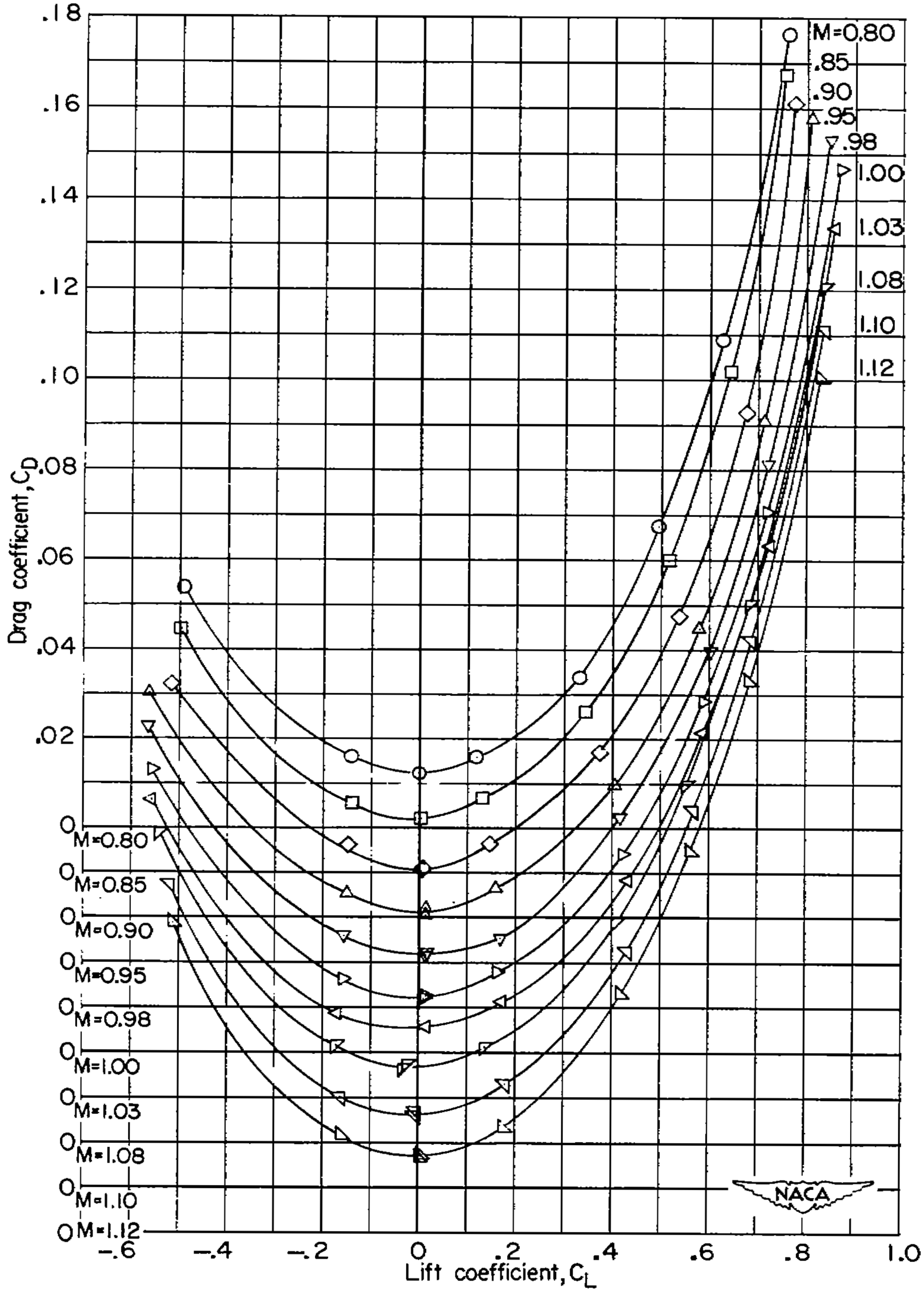
Figure 5.- Continued.

[redacted]



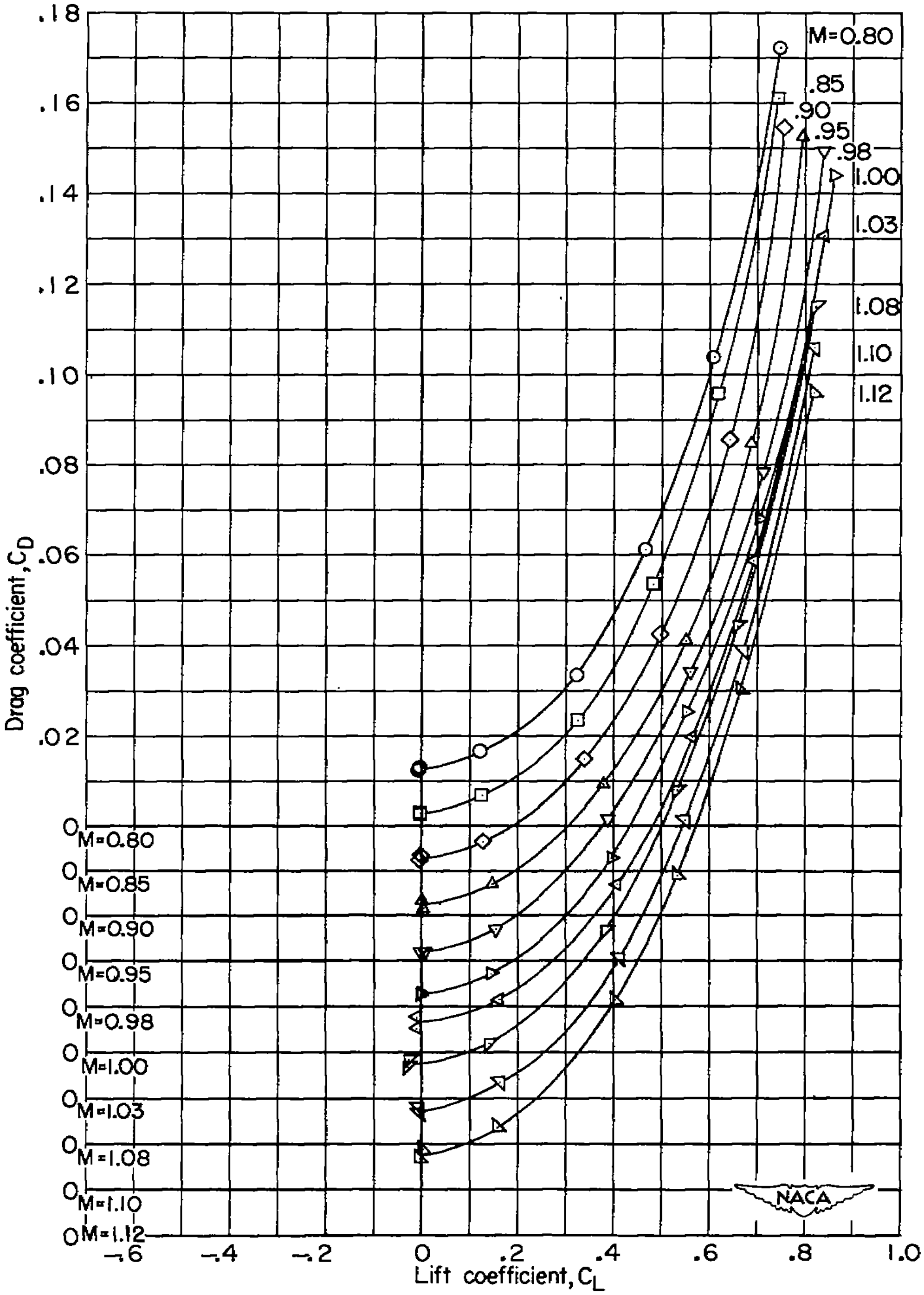
(c) Body modification C.

Figure 5.- Concluded.



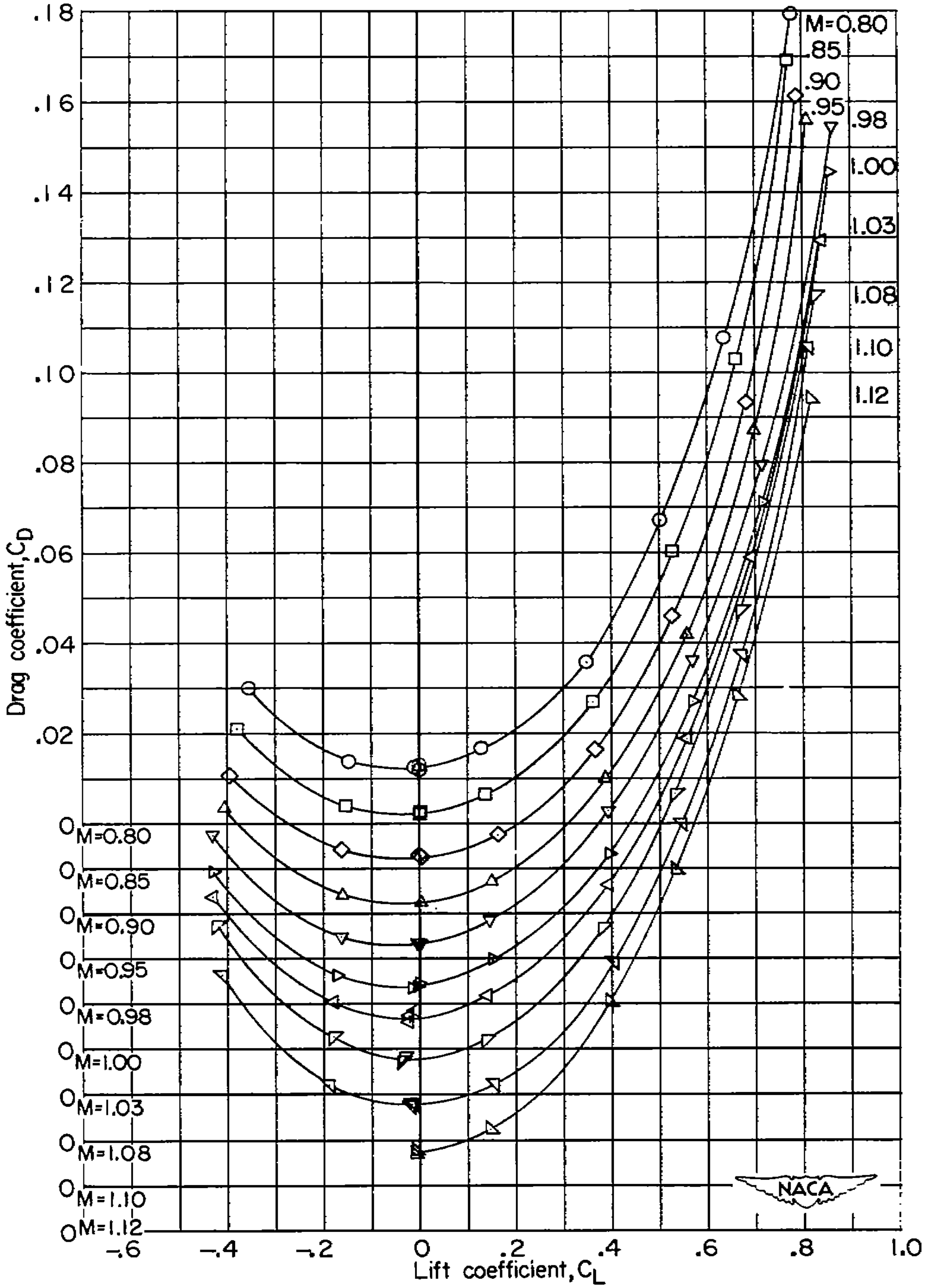
(a) Body modification A.

Figure 6.- Variation with lift coefficient of the drag coefficient of the various wing-body combinations at Mach numbers from 0.80 to 1.12.



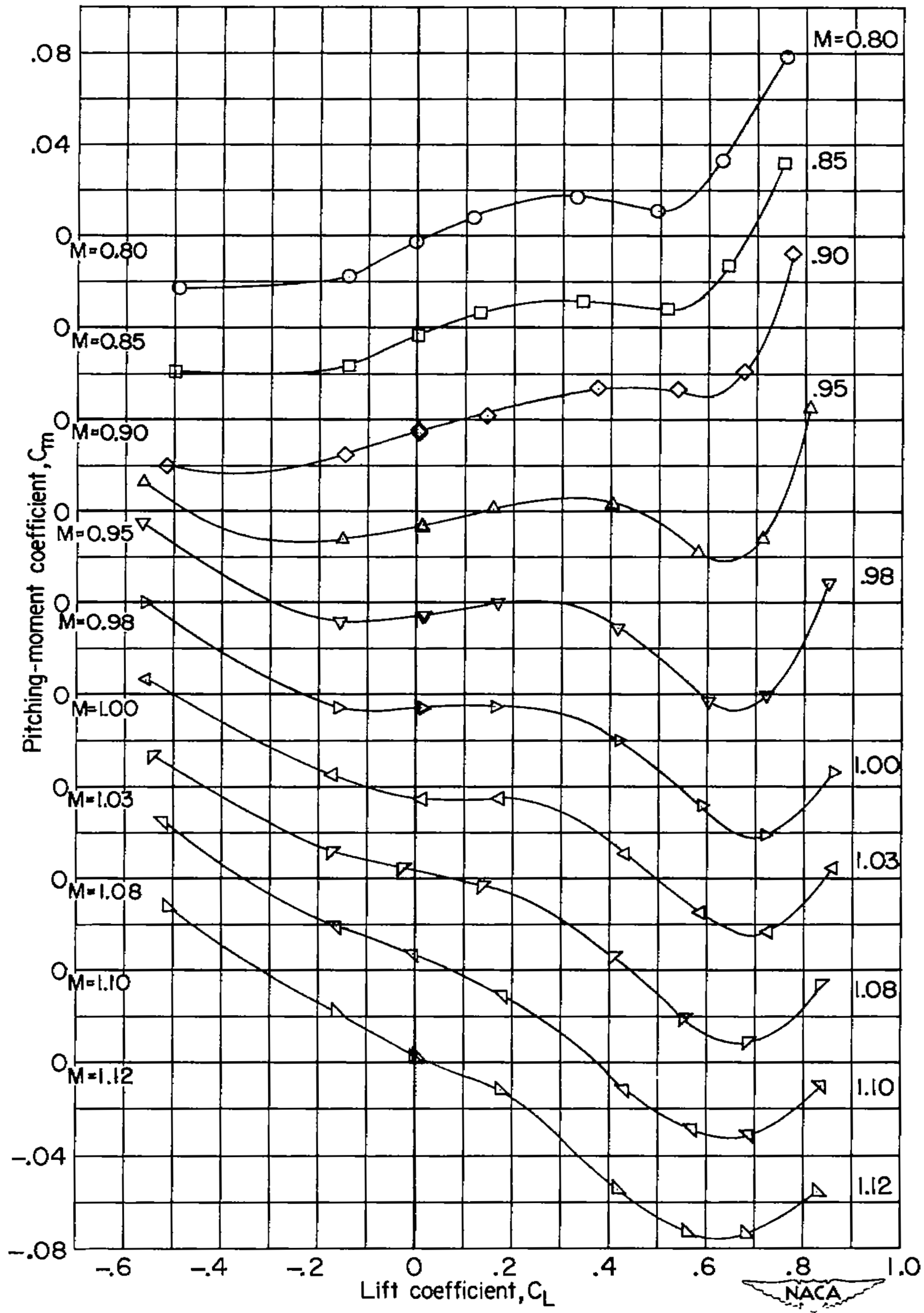
(b) Body modification B.

Figure 6.- Continued.



(c) Body modification C.

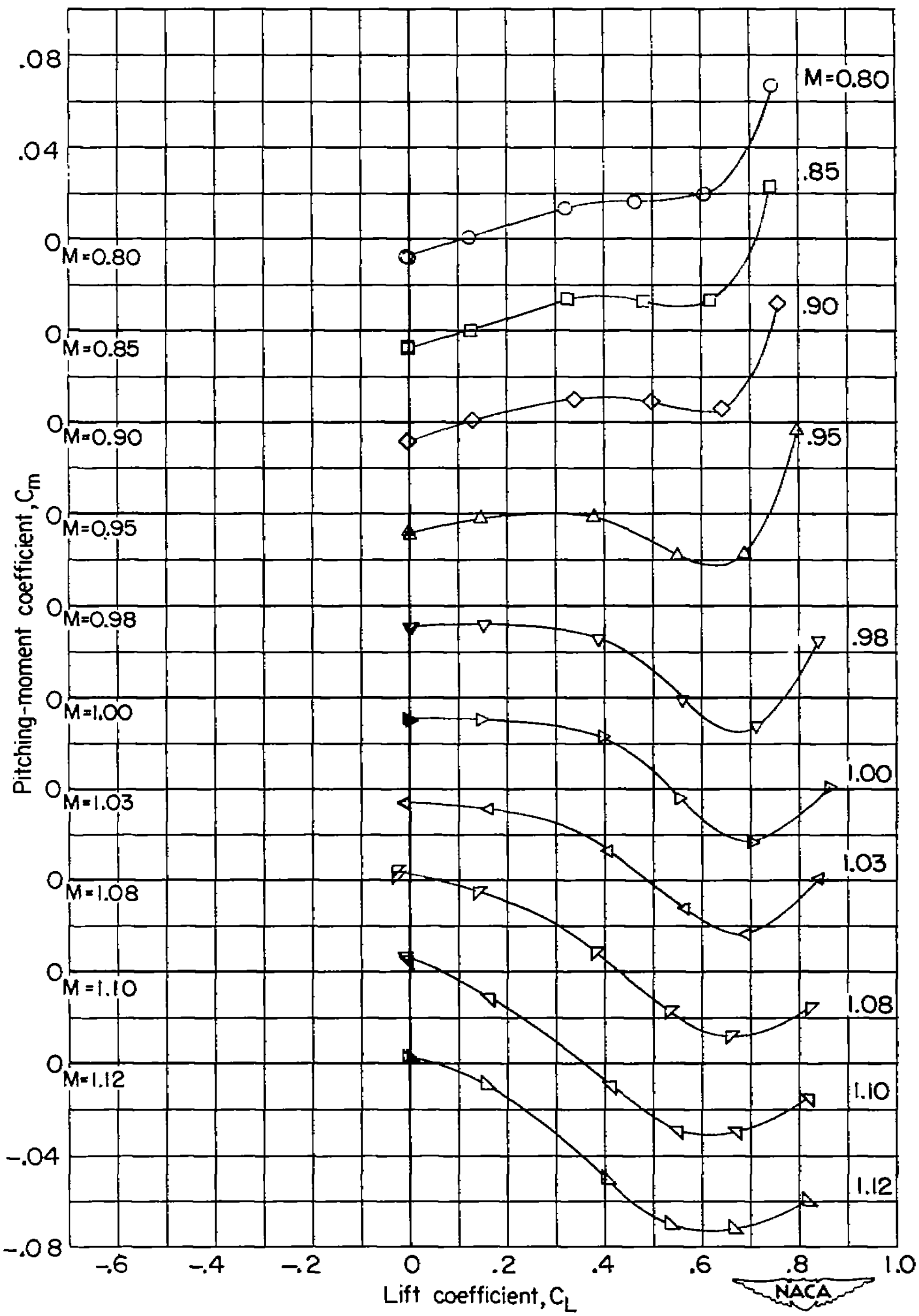
Figure 6.- Concluded.



(a) Body modification A.

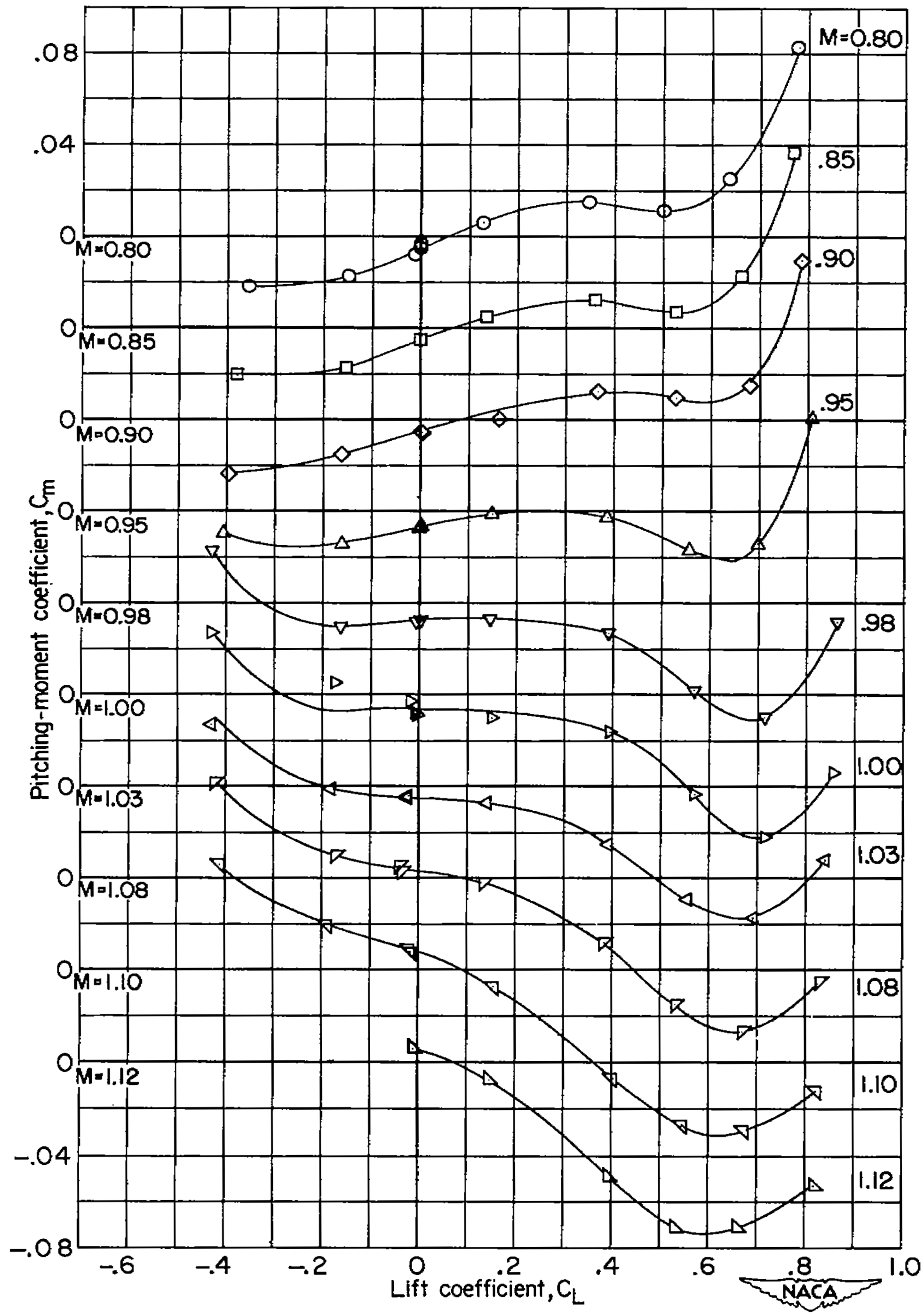
Figure 7.- Variation with lift coefficient of the pitching-moment coefficient of the various wing-body combinations at Mach numbers from 0.80 to 1.12.

[redacted]



(b) Body modification B.

Figure 7.- Continued.



(c) Body modification C.

Figure 7.- Concluded.

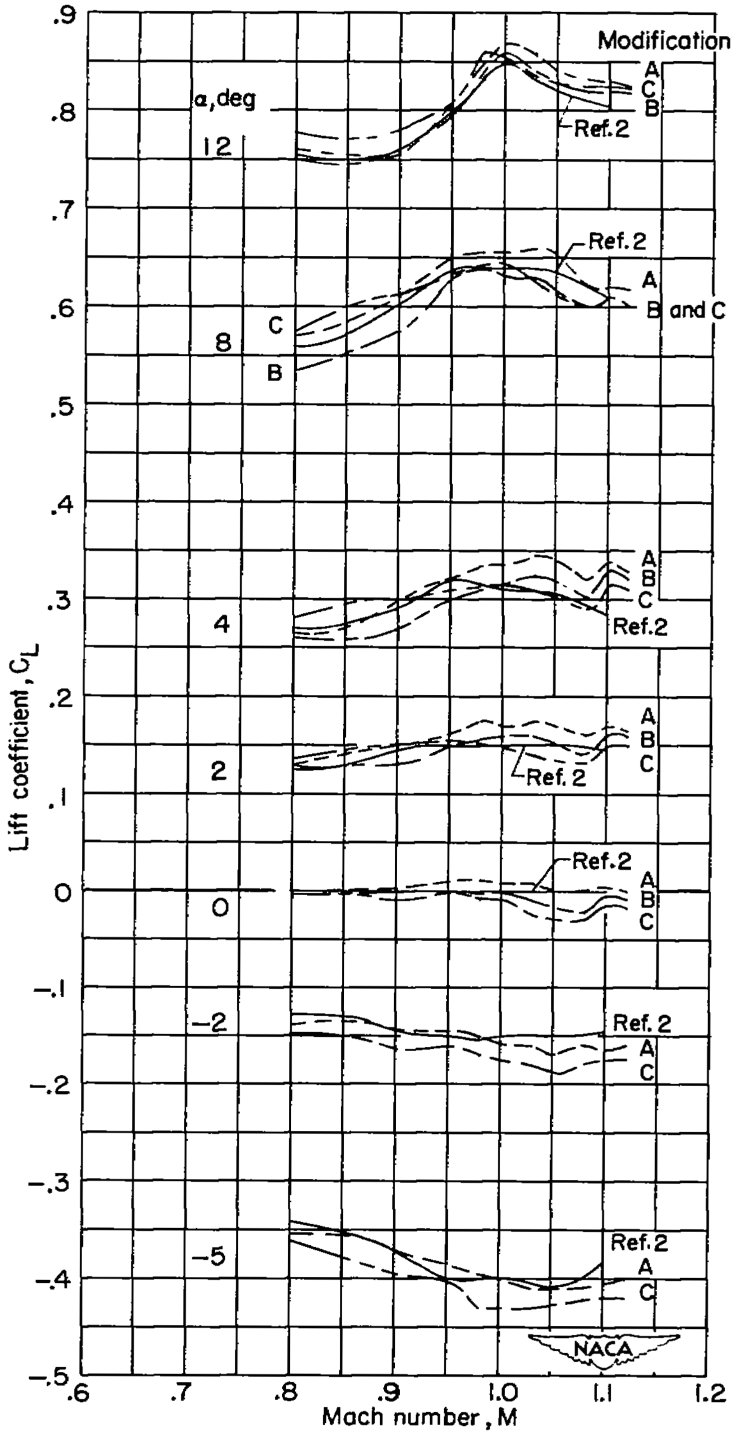


Figure 8.- Variation with Mach number of the lift coefficient of the various modifications at several angles of attack.

[redacted]

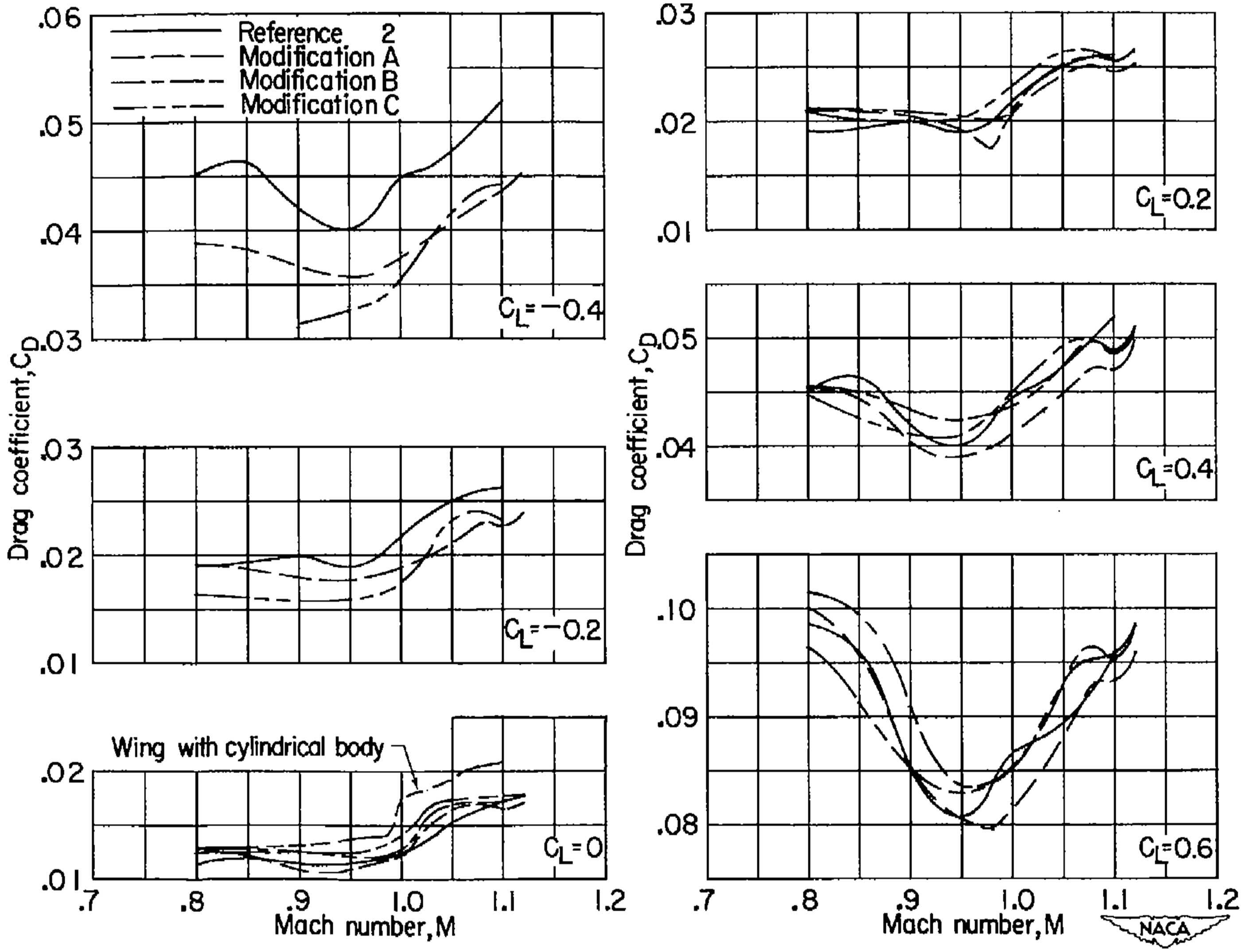


Figure 9.- Variation with Mach number of the drag-coefficient of the various wing-body combinations at several lift coefficients.

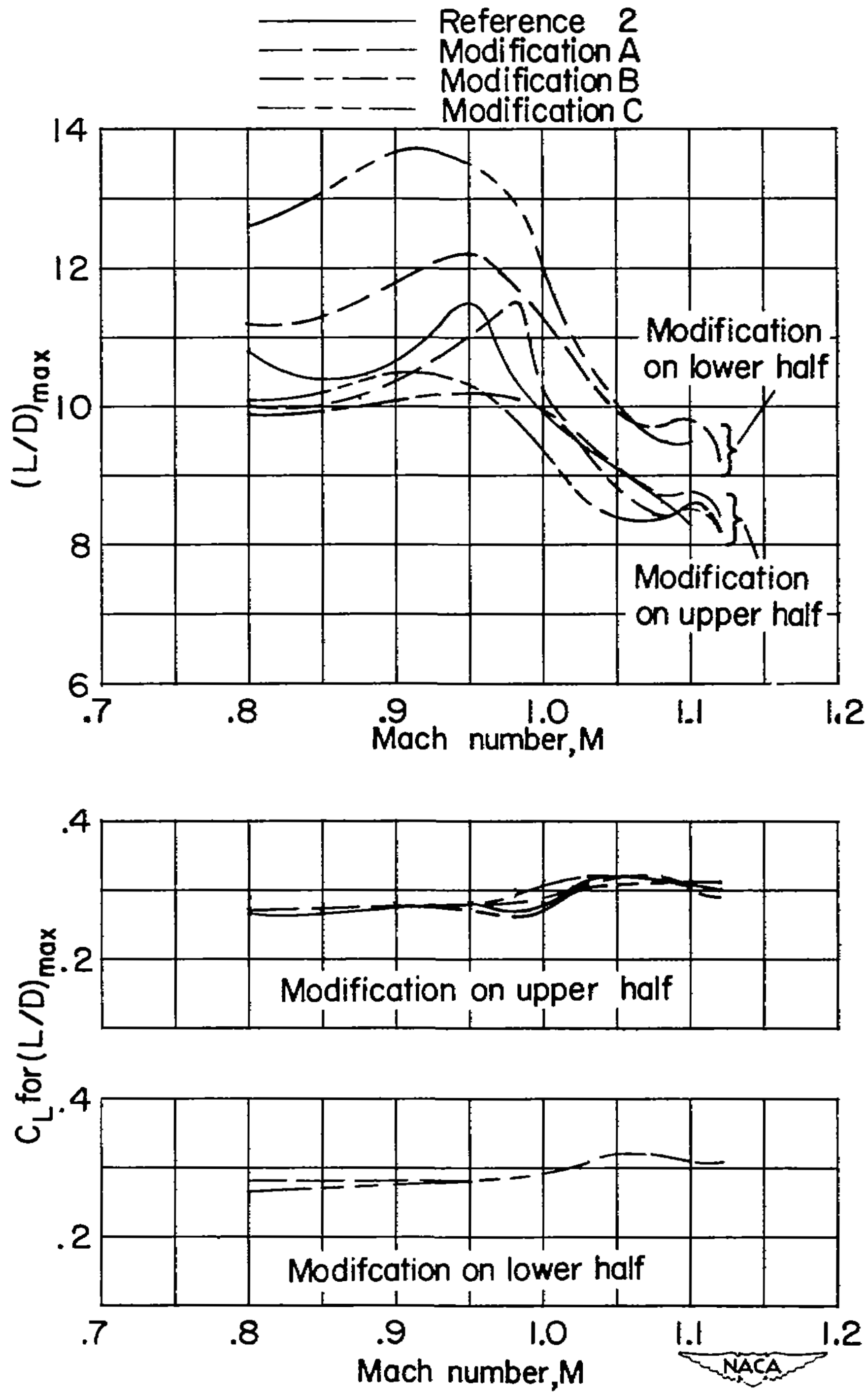


Figure 10.- Variation with Mach number of the maximum lift-drag ratio and the lift coefficient for maximum lift-drag ratio for the various wing-body combinations.

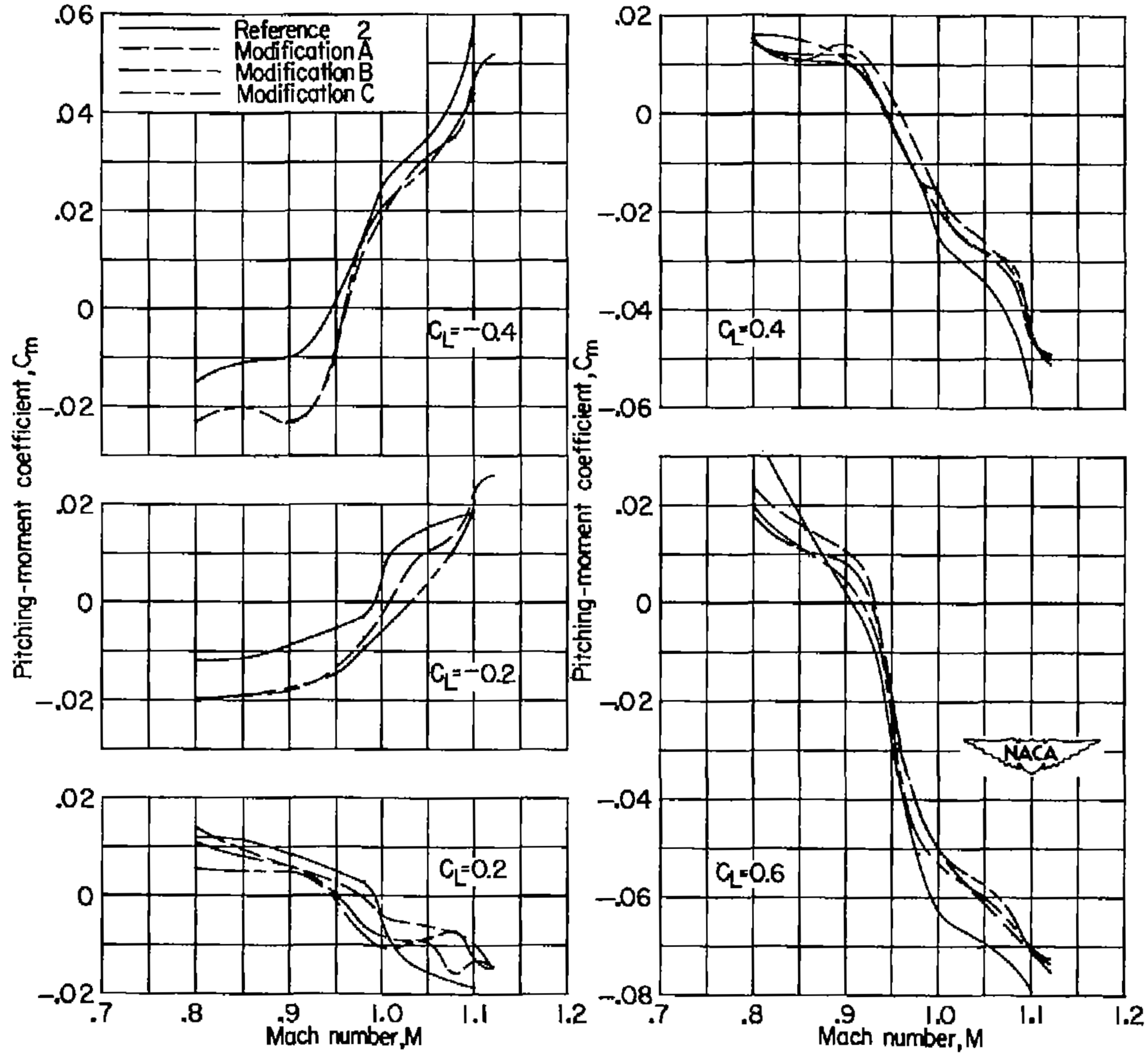


Figure 11.- Variation with Mach number of the pitching-moment coefficient of the various wing-body combinations at several lift coefficients.

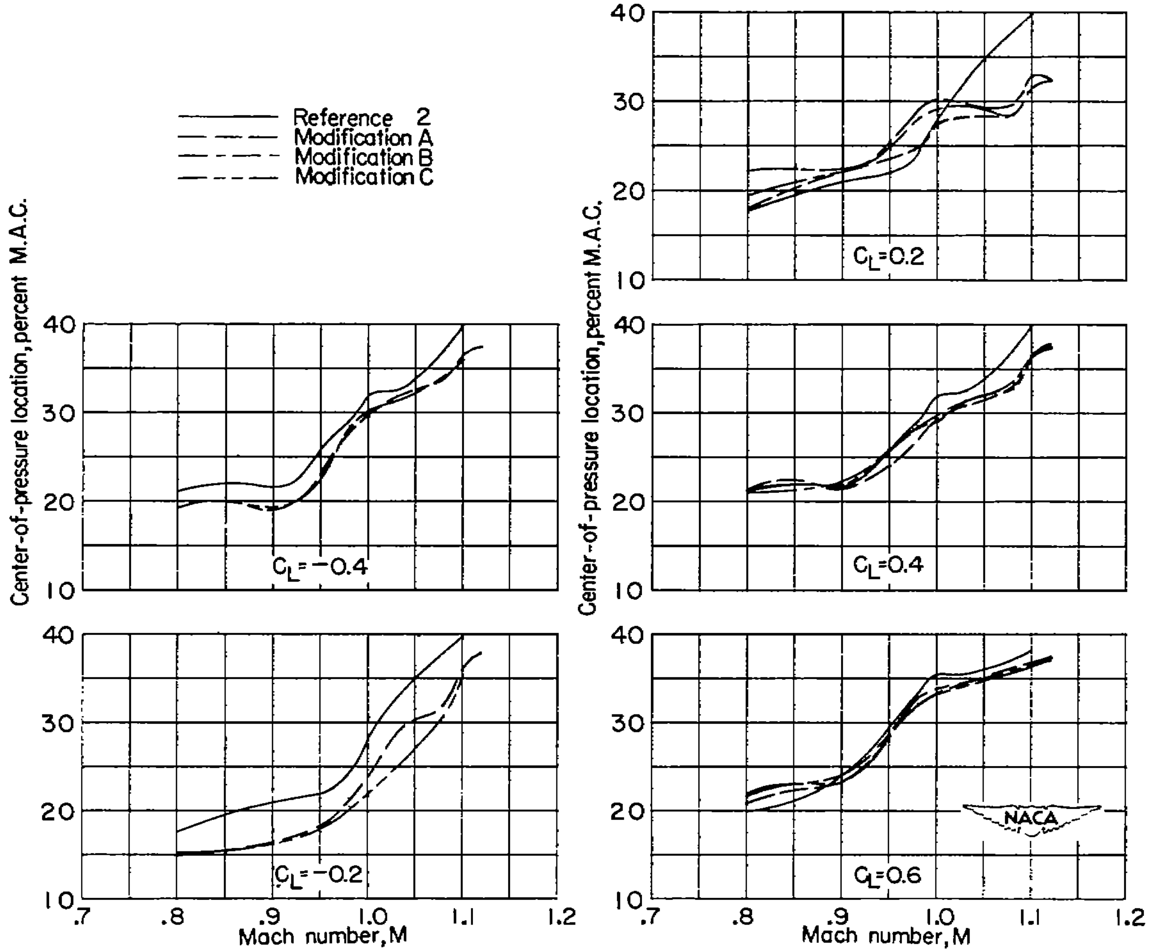


Figure 12.- Variation with Mach number of the longitudinal center of pressure location of the various wing-body combinations at several lift coefficients.